

2012 Advanced Space Propulsion Workshop

FFRE Powered Spacecraft

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What is **NIAC** ?
NASA Innovative Advanced Concepts

NASA Innovative Advanced Concepts

A program to support early studies of innovative, yet credible visionary concepts that could one day “change the possible” in aerospace





Exploration Technology Today

An Analogy



Launch



Exploration Technology Today

An Analogy



Staging



Launch





Exploration Technology Today

An Analogy



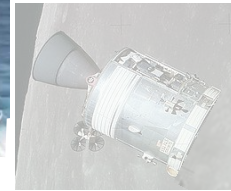
Launch



Staging



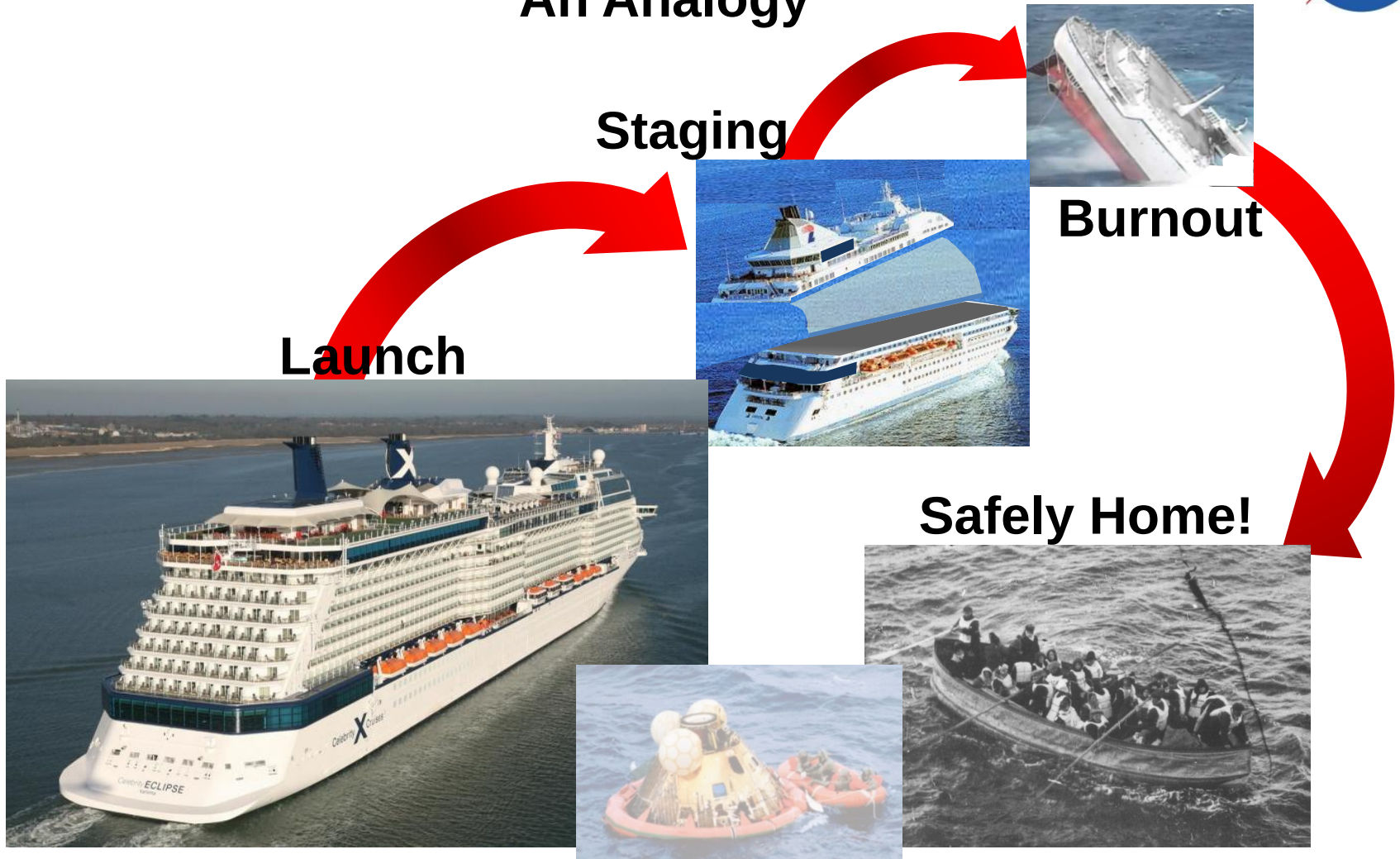
Burnout





Exploration Technology Today

An Analogy



Why Would You Want To Explore Like This?

Because
That's The
Best We
Can Do
Now



Because
That's The
Best We
Can Do
Now



A FISSION FRAGMENT ROCKET ENGINE:

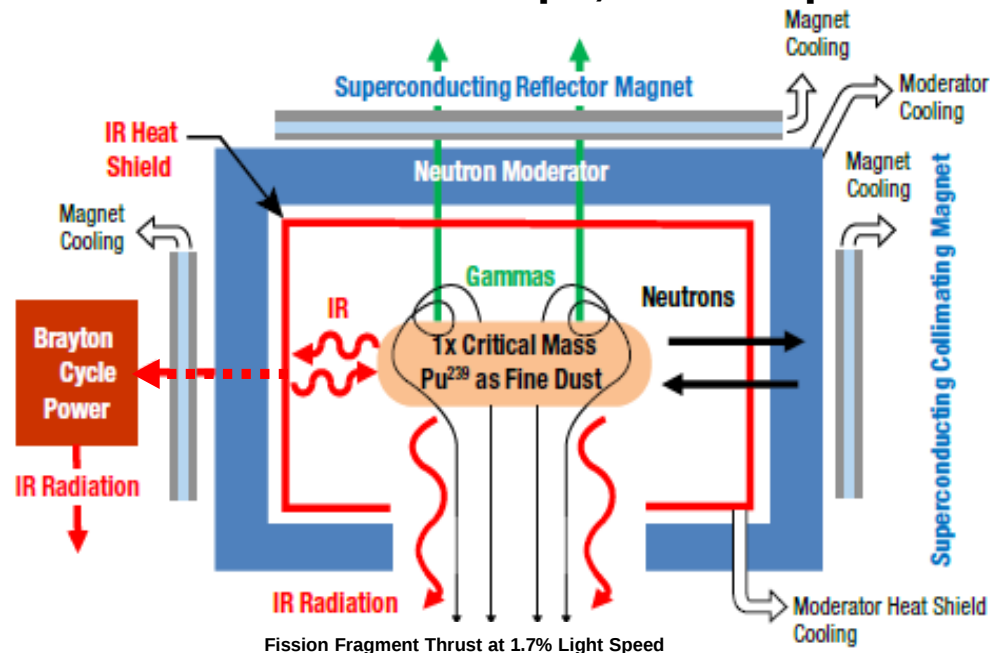
Engine Attributes:

- Far Less Propellant Than Chemical Or Nuclear Thermal ($I_{sp} \sim 500,000s$)
- Far More Efficient Than Nuclear Electric (100X Thrust)
- Far Safer Than Nuclear Thermal (Charge Reactor In Orbit, Radiation Leaves Solar System At >1% Light Speed)

Spacecraft Impact:

- More Payload
- Faster Travel
- Unlimited Electrical Power
- Enhanced Astronaut Safety

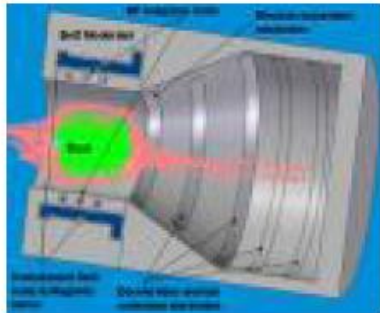
- ☐ **Reactor Core Uses Submicron Uranium Dust Grains**
- ☐ **Fissioning Low-Density Dust Is Radiatively Cooled.**
- ☐ **Moderator Reflects Neutrons To Keep Dust Critical**
- ☐ **Carbon-Carbon Heat Shield Reflects IR Away From The Moderator.**
- ☐ **Superconducting Magnets Direct FFs Out Of Reactor.**
- ☐ **Electricity Is Generated From Heat Shield Coolant**
- ☐ **Reactor Hole Provides: Heat Escape, FF Escape At 1.7% Light-Speed**





Original Spinning Brush FFRE

1986: George Chapline's "Spinning Brush" FFRE: Uranium coated carbon fiber permits half the fission fragments to escape, providing thrust. The other half heats up so fibers rotated out of reactor to cool.



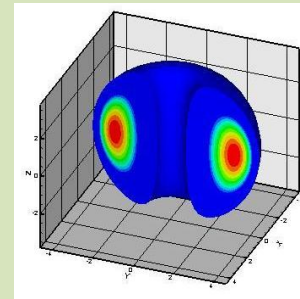
Dusty Plasma FFRE Creation

2005: Dr. Rod Clark creates "Dusty Plasma" FFRE: Fissioning uranium dust maximizes both fission fragment escape and radiative cooling, increasing efficiency and permitting reactor operation at Gigawatts of power.

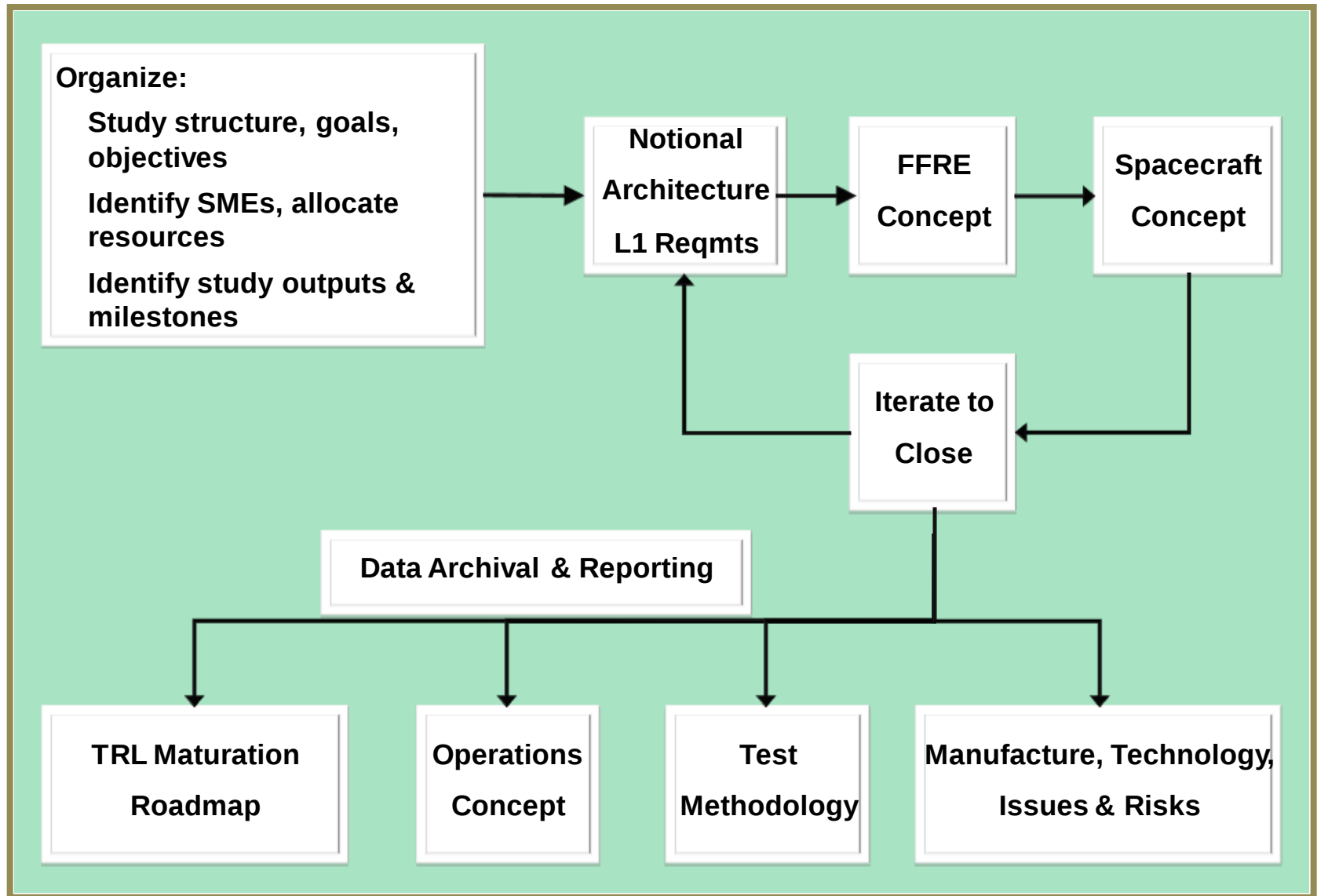
Grassmere Dynamics, LLC

- **Engineering & Consulting**
- **40 Years Of Combined Experience In Engineering Design, Materials, Testing & Quality Assurance.**
- **Specialty Modeling Skills:**
 - Computational Fluid Dynamics (CFD)
 - Magneto Hydrodynamic Plasma (MHD)
 - Nuclear (Radiation, Reactor Design & Performance)
 - Optical

3D Simulation Of Tokamak Nuclear Fusion Reactor Magnetically Confined Plasma Using Grassmere Code

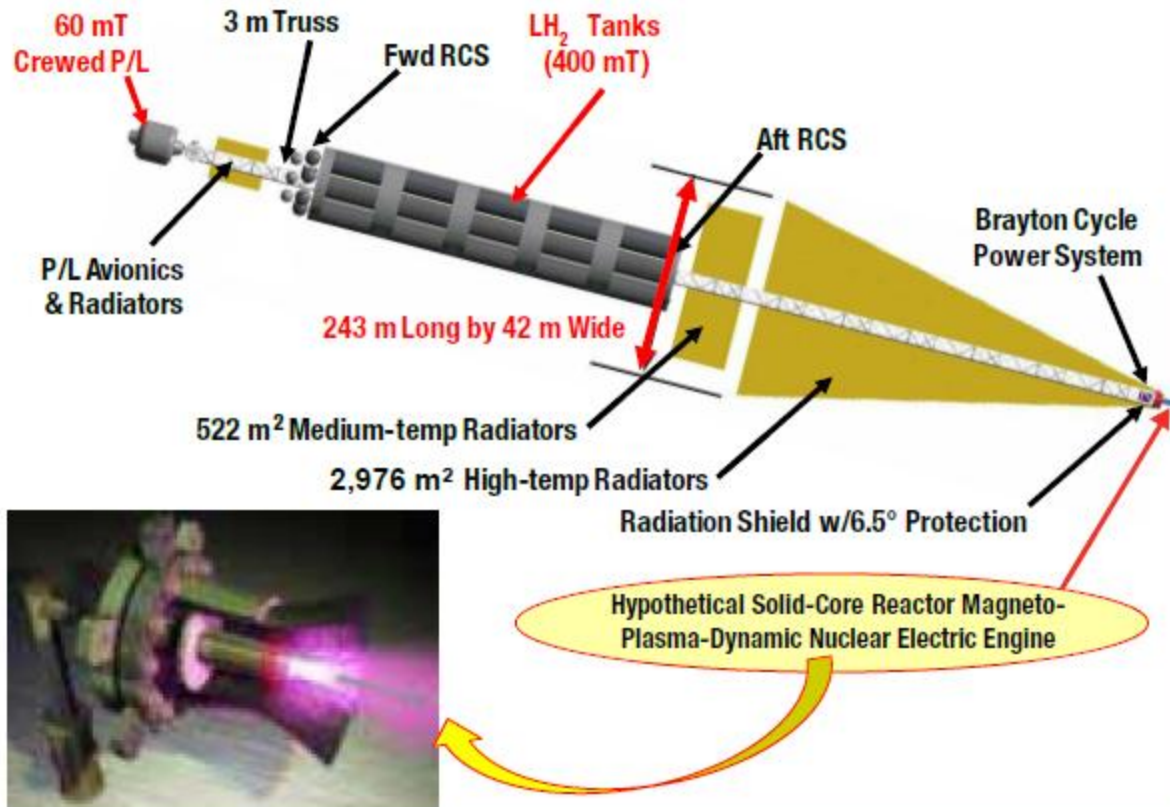


Study Approach

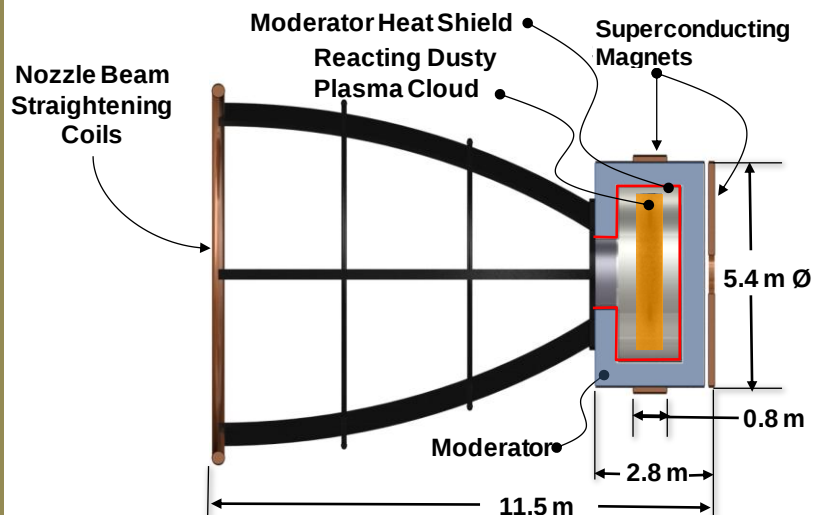


Spacecraft and mission based on 2004 Human Outer Planet Exploration (HOPE) study

- 60 mT crewed payload on roundtrip mission to Callisto
- Propulsion was hypothetical nuclear electric magneto-plasma-dynamic thrusters (6 NEMPD engines, 33 MW each, providing ~22-lb thrust at 8,000 s delivered I_{sp} using hydrogen as propellant)
 - 1 FFRE substituted for 6 NEMPD engines
- All impacted spacecraft subsystems to be redesigned



Base FFRE Design



Master Equip List Mass incl 30% MGA

FFRE System Total, mT	113.4
Nozzle	6.4
Magnetic Mirror	28.6
Exit Field Coil	11.1
Moderator	51.2
Moderator Heat Shield	0.1
Control Drum System	0.7
Electrostatic Collector	0.3
Dust Injector	7.2
Shadow Shield	7.8

Distribution	(MW)
Total Reactor Power	1,000
Neutrons (30% to FFRE)	24.2
Gammas (5% to FFRE)	95.6
Other	70.2
Thermal (IR)	699
Jet Power	111
Performance	
Thrust	43 N (9.7 lbf)
Exit Velocity	5170 km/s
Specific Impulse	527,000 s
Mass Flow	0.008 gm/s

Revised FFRE Designs

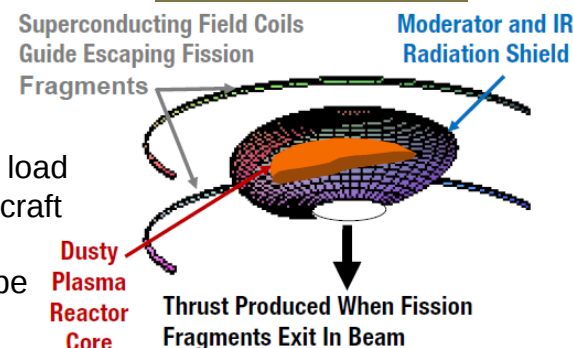
Attributes:

- ❑ Ellipsoid Moderator
- ❑ Ring Magnets

Assessment:

- ❑ Reduced heat load so less Spacecraft radiator mass
- ❑ Complex Shape Moderator
- ❑ Thrust & I_{sp} unchanged

Generation 1



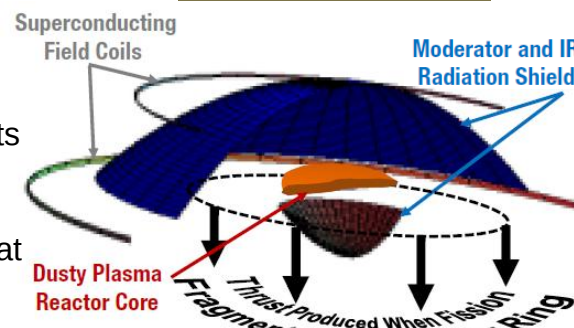
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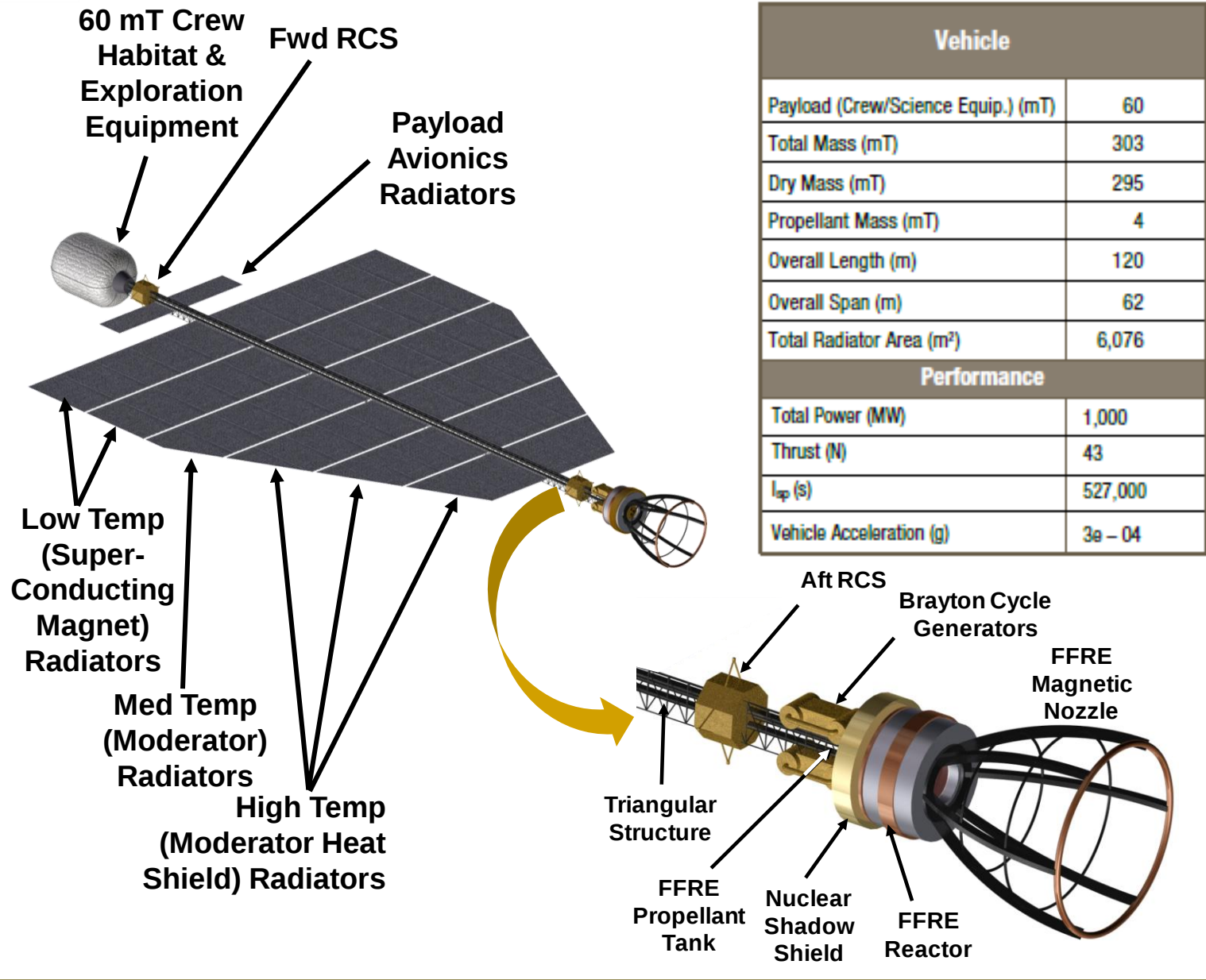
- ❑ Dual Paraboloid Moderator
- ❑ Ring Magnets

Assessment:

- ❑ Reduced heat load so less Spacecraft radiator mass
- ❑ Complex shape moderator, difficult to support & cool, weighs more
- ❑ Thrust: 2X (86 N, 19 lbf)
- ❑ I_{sp} unchanged (527,000 s)

Generation 2





Payload Packaging, hypothetical 12m shroud and >120mT capacity

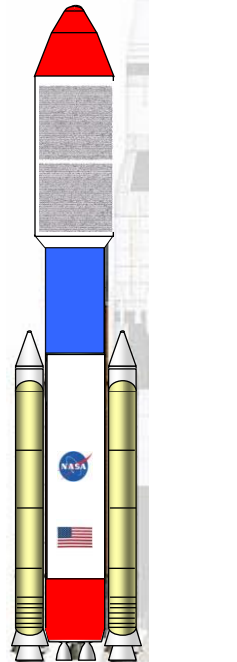
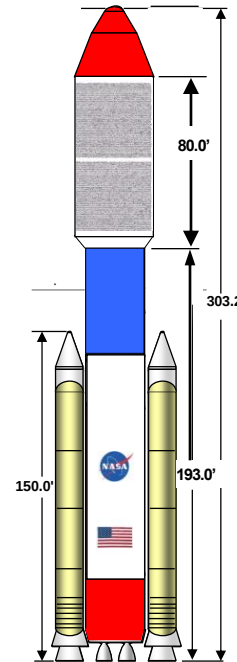
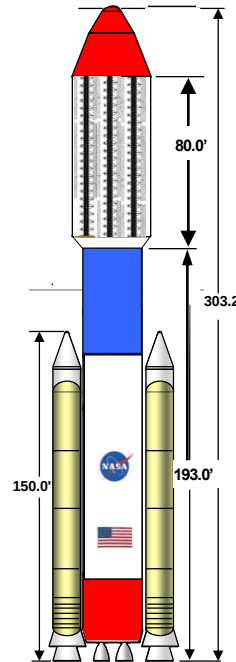
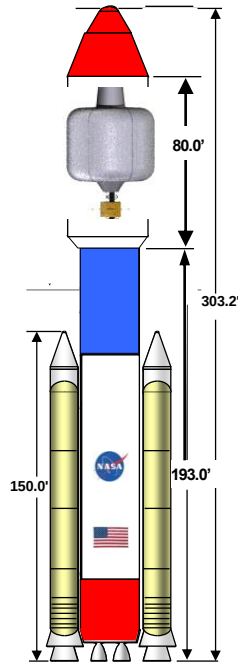
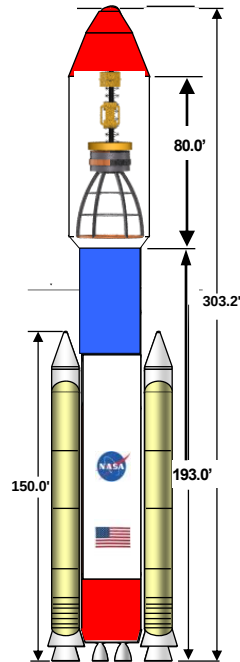
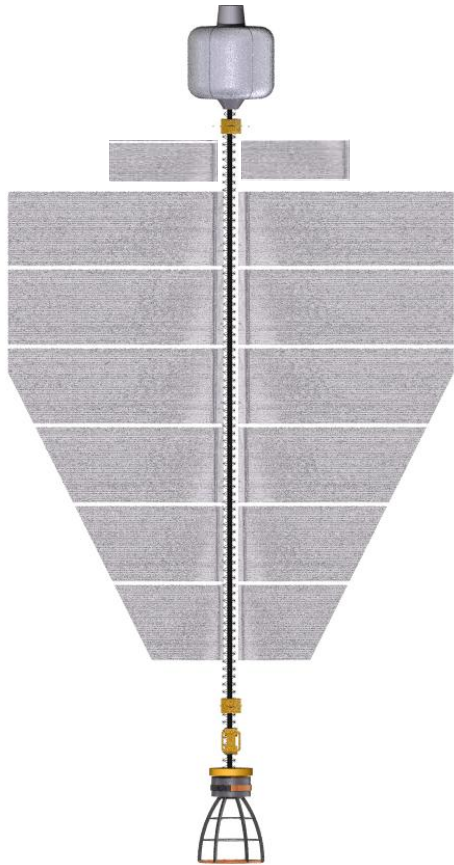
FFRE & Braytons

Crew & Avionics

Structure Backbone

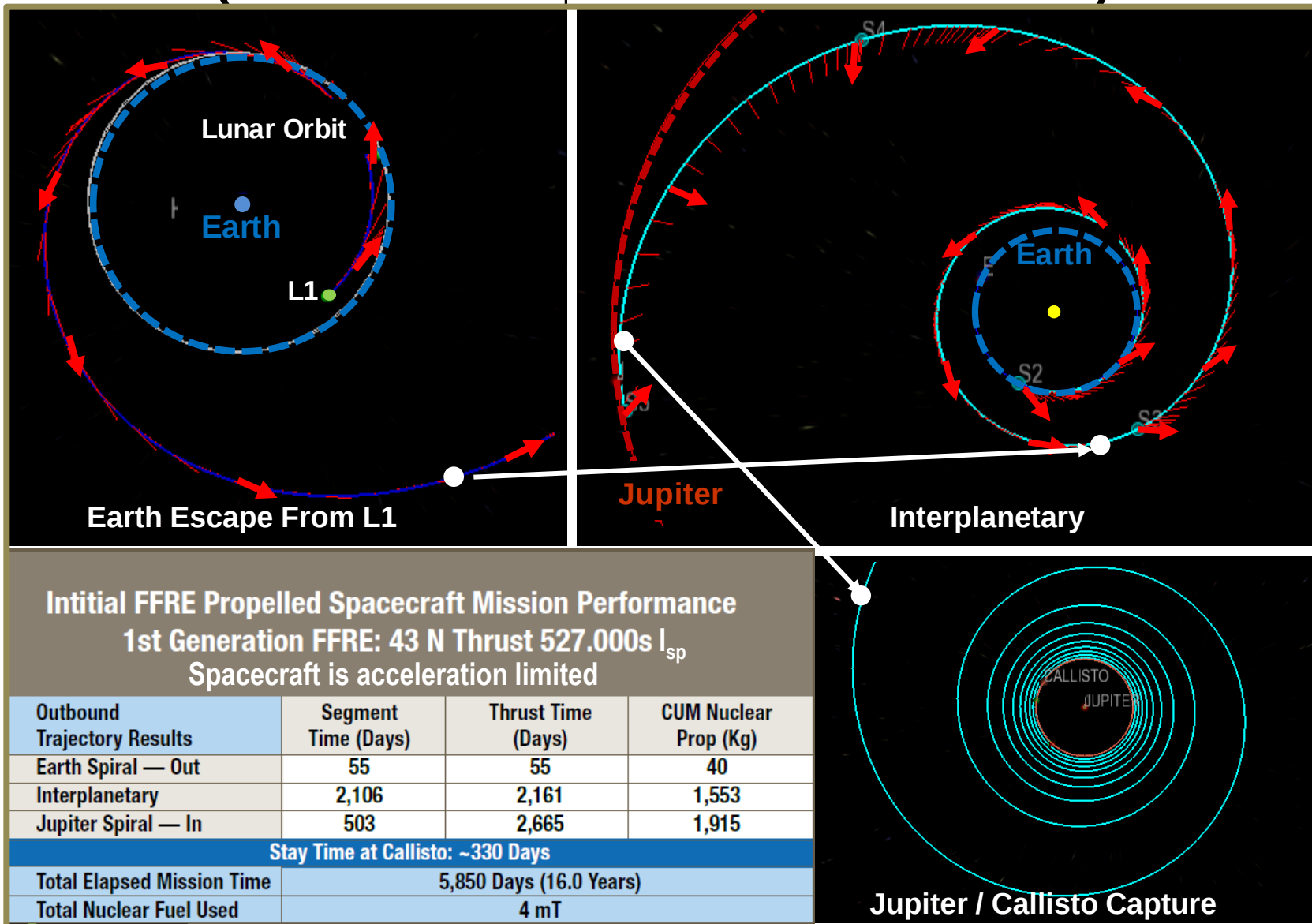
Radiator

Radiators



Spacecraft Performance

(First FFRE / Spacecraft Assessment)

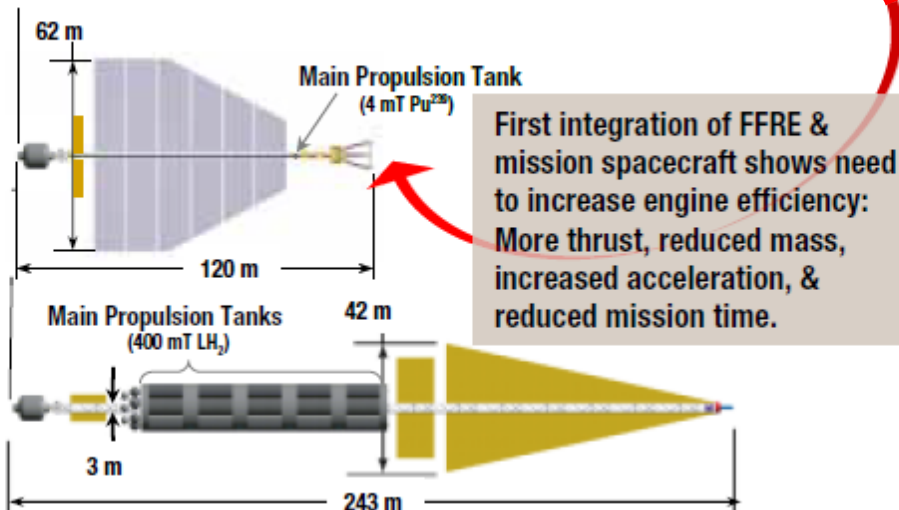


Vehicle	HOPE	FFRE
Payload (Crew/Science Equip) (mT)	60	60
Total Mass (mT)	890	303
Dry Mass (mT)	460	295
Propellant Mass (mT)	400	4
Overall Length (m)	243	120
Overall Span (m)	42	62
Total Radiator Area (m ²)	3498	6,076
Performance	HOPE	FFRE
Total Power (MW)	34	1,000
Thrust (lbf)	126	9.7
I_{sp} (s)	8,000	527,000
Vehicle Acceleration (g)	14e-4	3e-4
Outbound Trip Time (days)	833	2,665
Return Trip Time (days)	693	2,854
Total Mission (years)	HOPE 4.5yrs?	8-16 yrs

What Is Learned So Far

- ❑ A FFRE is credible – ordinary engineering, ordinary physics. NO MIRACLES.
- ❑ A FFRE-propelled spacecraft is game changing to travel in space. A spacecraft with a heavy payload can depart for and return from many solar system destinations. NO REASSEMBLY REQUIRED.
- ❑ Our first constructs of a FFRE are grossly inefficient. We are like a Ford Model T engine. Only a few ways of improving performance of the FFRE and spacecraft have been considered.

THERE'S MUCH WORK TO DO.



Effect on Mission Of 2nd Generation FFRE Design

FFRE

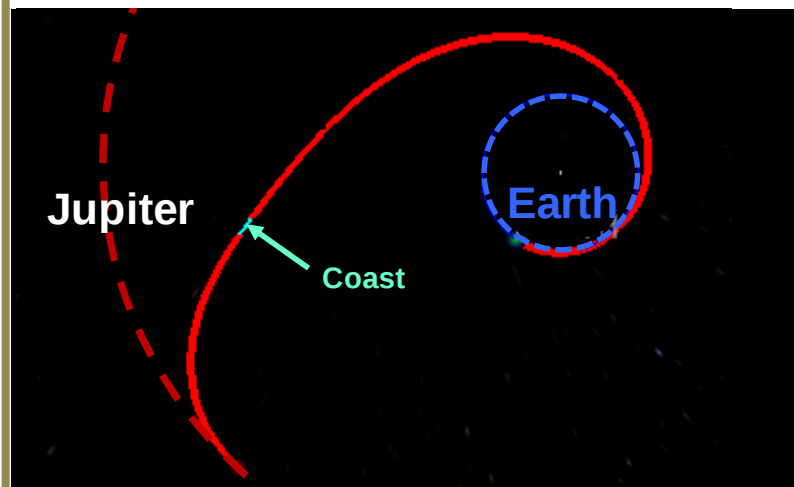
- ❑ Thrust: 2X (86N)
- ❑ I_{sp} : 527,000s

Spacecraft

- ❑ Assumed no change (conservative)

Mission

- ❑ ~8 years round trip
- ❑ Spiral out and in times halved
- ❑ Small coast period in interplanetary flight
- ❑ Propellant: ~4 mT nuclear



Effect on Mission Of Adding an “Afterburner “ to FFRE Design

FFRE

- ❑ Fission fragments accelerate an inert gas added to nozzle via friction, adding thrust & decreasing specific impulse

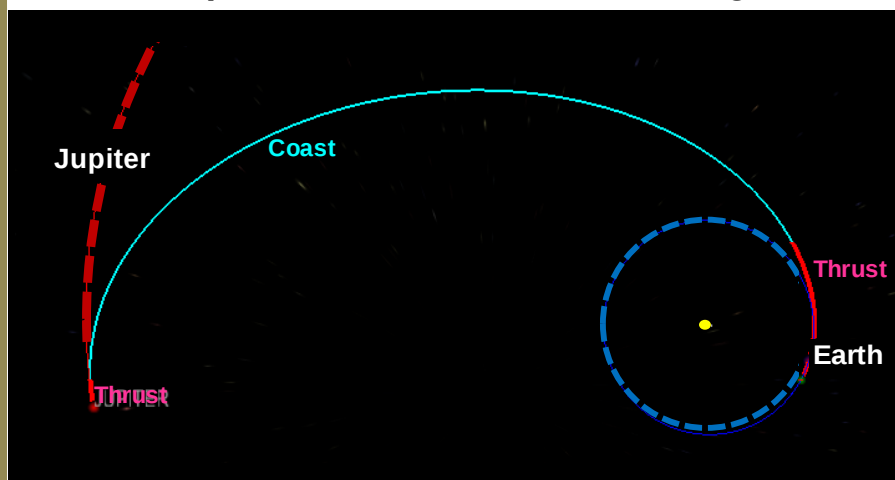
- ❑ Thrust: 430N, I_{sp} : 52,700s (notional)

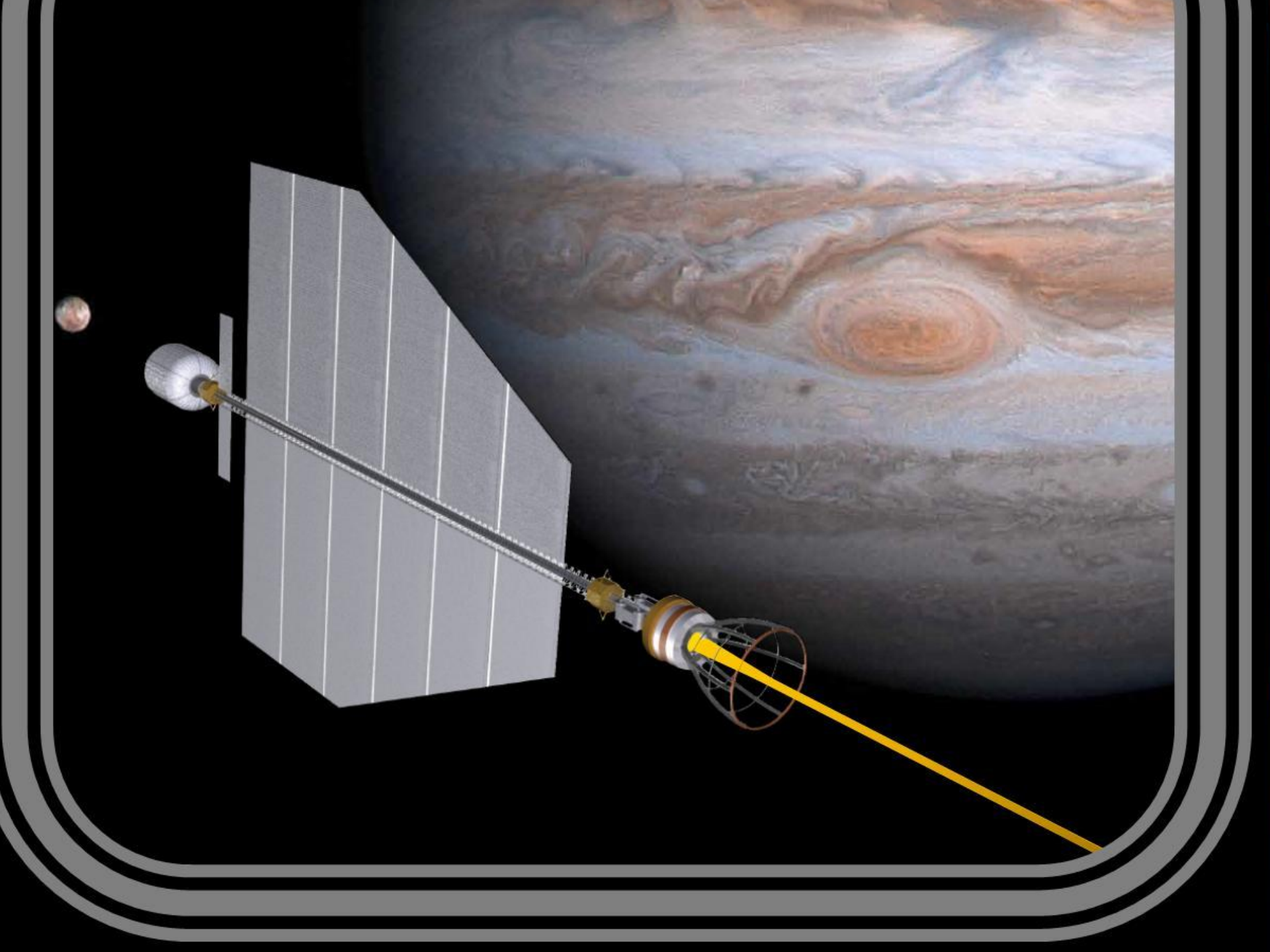
Spacecraft

- ❑ Added “propellant” and tankage

Mission

- ❑ ~6 years round trip
- ❑ From Earth: 4 days, Into Jupiter: 40 days
- ❑ Interplanetary Coast: 950days
- ❑ Propellant: 0.3mT nuclear, 22mT gas





Lighting The Afterburner On A Fission Fragment Rocket Engine

FY 13 Center Innovation Fund Study Award

The Next Step:

